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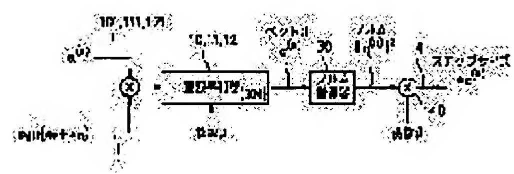
(54) ADAPTIVE FILTER AND STEP SIZE CONTROL METHOD AND RECORDING MEDIUM FOR RECORDING PROGRAM

(57)Abstract:
PROBLEM TO BE SOLVED: To provide an adaptive filter for controlling a step size so that a residual error after convergence can be reduced, and the high speed of convergence can be attained.
SOLUTION: This is an adaptive filter equipped with a non-recursive filter which uses a probability gradient LMS algorithm. The norm of a vector obtained by averaging the vector of a product obtained by multiplying the polarity of the sum of an error signal and an additive noise by a filter input signal vector by leakage accumulators 10, 11, and 12 is calculated by a norm calculator 30, and a value obtained by multiplying this norm by a preliminarily applied coefficient is obtained as a step size 4.



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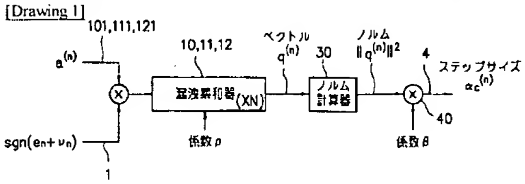
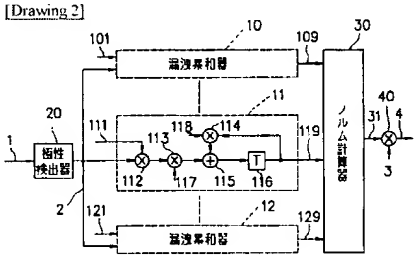
DRAWINGS

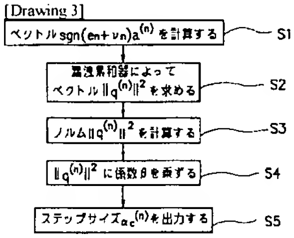
[Drawing 1]



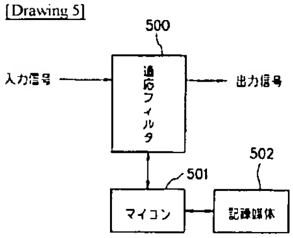
[Drawing 2]



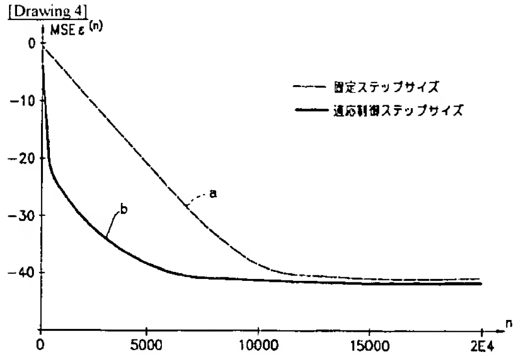
[Drawing 3]



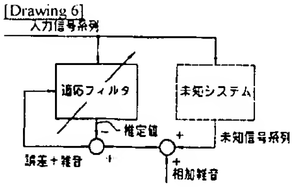
[Drawing 5]



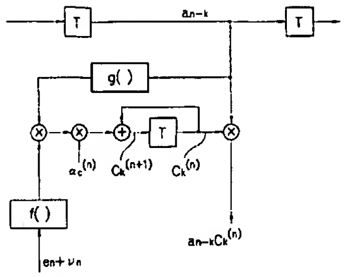
[Drawing 4]



[Drawing 6]



[Drawing 7]



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DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] It is the block diagram showing the gestalt of operation of the 1st of this invention notionally.
[Drawing 2] It is the block diagram showing the detailed configuration of drawing 1 .
[Drawing 3] It is the flow chart which shows processing of the step size control approach.
[Drawing 4] It is the property Fig. of the simulation result of the adaptation filter in which the effectiveness of the gestalt of the 1st operation is shown.
[Drawing 5] It is the block diagram showing the gestalt of operation of the 2nd of this invention.
[Drawing 6] It is the block diagram showing the principle of an adaptation filter.
[Drawing 7] It is a block diagram for explaining the tap weight control algorithm of a non-going round round mold adaptation filter.
[Description of Notations]
1 Input
20 Polar Detector
2 Polar Output
101, 111, 121 Leakage ****** input
10, 11, 12 Leakage ******
112, 113, 114 Multiplier
115 Adder
116 Delay Circuit
117 Leakage Factor
118 Complement of Leakage Factor
109, 119, 129 Leakage ****** output
30 Norm Calculator of Vector
31 Norm
40 Multiplier
3 Multiplier
4 Output Step Size

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] This invention relates to the record medium which recorded the step size control approach used with the echo canceller and the automatic equalizer for digital data transmissions which are used for data transmission or a sound system, the adaptation filter generally used for identification of an unknown system, and this adaptation filter, and the program.
[0002]
[Description of the Prior Art] The principle of an adaptation filter is described first. The principle Fig. of an adaptation filter is shown in drawing 6 . An adaptation filter creates the estimate of a known filter input signal sequence to a strange signal sequence, updates the parameter which a filter has based on the signal sequence of the error of a strange signal sequence and this estimate sequence, and identifies an unknown system correctly. Additive [of the noise at the time of observation] is usually carried out to a strange signal sequence. An adaptation filter is converged on a final state from a non-learned initial state. Moreover, a strange signal sequence is given as a response to the input signal sequence which the unknown system mentioned above in many cases. An echo canceller and an automatic equalizer correspond in this case.
[0003] It realizes as a non-going round round mold (FIR) in many cases, and an adaptation filter serves as a configuration shown in drawing 7 . This Fig. is k. The control circuit of the tap weight of eye watch is shown. It is an error signal sequence here. en Noise sequence nun The sum is used and it is N. The tap weight c0 and c1 of an individual, ..., cN-1 Each multiplier is controlled. It is n in this Fig. Time of day and an An input signal sequence and alphac (n) Time of day n It is the step size which can be set. The general probability inclination control algorithm of the tap weight shown in this drawing is given by the degree type.
c(n+1) = c (n) +alphac (n) f g (en+nun) (a (n)) .... (1) [0004] here -- c (n) = [c0 (n), c1 (n), ..., cN-1 (n)] T and -- a (n) =[an, an-1, ..., an-N +1] T Tap weight and an input signal sequence are expressed as a vector, respectively, and both function f() and g() are odd functions, and, generally nonlinear. Moreover, g (a (n)) Vector (g (an), and [g (an-1), ..., g (an-N +1)]) T It means and is []. T A vector or the transpose of a matrix is shown.
[0005] As a control algorithm of the tap weight of an adaptation filter To what is used with a sufficient industry top Probability inclination LMS algorithm: f(x) =x, g () [a] (n) -- (n) probability inclination sign DORIGURESSA algorithm: -- f(x) =x and g = a(n) probability inclination normalization LMS algorithm: -- f(x) =x and g(a (n)) = a (n) () /Pa and Pa= a(n) T a [a] (n) = sgn (a (n)) probability inclination sign algorithm: -- f(x) = -- there are sgn (x) and g(a (n)) = a(n) probability inclination sign-sign algorithm:f(x) =sgn(x), g(a (n)) = sgn (a (n)), etc. However, sgn() is a polar function.
[0006] Next, how to choose a step size is described. Although a step size is a parameter which determines the convergence time amount of a multiplier, and the amount of residua after convergence, when the value of this step size is considered as immobilization, if it chooses greatly in the range in which convergence of a filter becomes stable, convergence is quick, but when an additive noise exists, the power of the residuum after convergence will become large. Conversely, a convergence rate becomes slow, although the residuum after convergence will be small suppressed if a step size is chosen small. Then, if adaptive control of the step size is carried out in early stages of convergence of a filter so that it may become small as it is large and convergence progresses, the small adaptation filter of the residuum after convergence with quick convergence is realizable.
[0007] as the adaptive control approach of the conventional step size -- error gradient method (1) An error and replica correlation technique (2) Fourth statistic method (3) etc. -- it is proposed. These are detailed in the following reference.
(1) V.J.Mathews et al.,"A Stochastic-Gradient Adaptive-Filter-with Gradient-Adaptive-Step Size," IEEE Trans. on SP, vol.41, no.6, pp.2075-2087,June 1993.(2) A.Kanemasa et-al.,"An-Adaptive-Step-Sign-Algorithm for Fast Convergence-of-a-Data Echo-Canceller and "IEEE Trans.on Commun. and vol.35, no.10 and pp.1102-1108, October1987. (3) D.Pazaitis et al. and "A Kurtosis-DrivenVariable Step-Size LMS Algorithm" Proceedings IEEE ICASSP96, vol.III, and pp.1846-1849, Atlanta, GA, May 1996. [0008] furthermore, the approach the approach of changing the magnitude of a step size to JP,8-265223,A according to the magnitude of the absolute value of tap weight changes a step size to JP,2-291712,A by the variance of error signal power -- moreover, the method (refer to above (2)) of changing a step size according to the polarity of an error signal and the polar correlation value of an adaptation filter output (estimate or replica) is indicated by JP,61-234131,A.
[0009]
[Problem(s) to be Solved by the Invention] However, the above (1) - (3) It is known for the conventional approach that effectiveness is not all enough. When it was going to suppress especially the residuum after convergence small to extent obtained with the step size of immobilization, there was a problem that sufficient improvement in improvement in the speed of a convergence rate was not obtained.
[0010] Therefore, the convergence rate of this invention is quick and it is to realize the small adaptation filter of the residuum after convergence using the adaptive control approach of a different step size from what was indicated by each above-mentioned number official report.
[0011]
[Means for Solving the Problem] In the adaptation filter by this invention, in order to attain the above-mentioned purpose A detection

means to detect the polarity of the error signal of a filter output signal and a strange signal, The 1st multiplication means which multiplies the polarity which carried out [above-mentioned] detection by the filter input signal vector, and acquires the vector of a product, A leakage **** means to equalize the vector of the above-mentioned product, an operation means to compute the norm of the vector of the product which carried out [above-mentioned] equalization, and the 2nd multiplication means that multiplies the norm by which calculation was carried out [above-mentioned] by the predetermined multiplier, and obtains a step size are established.
[0012] Moreover, in the step size control approach by this invention, the procedure which calculates the norm of the vector which equalizes the vector of the product which multiplies the polarity of an error signal by the filter input signal vector, and is obtained, and is acquired, and the procedure of multiplying the above-mentioned norm by the predetermined multiplier, and obtaining a step size are formed.
[0013] Furthermore, it sets to the record medium which recorded the program by this invention. The detection processing which detects the polarity of the error signal of the filter output signal of an adaptation filter, and a strange signal, The 1st multiplication processing which multiplies the polarity which carried out [above-mentioned] detection by the filter input signal vector, and acquires the vector of a product, The program for performing leakage **** processing which equalizes the vector of the above-mentioned product, data processing which computes the norm of the vector of the product which carried out [above-mentioned] equalization, and 2nd multiplication processing which multiplies the norm by which calculation was carried out [above-mentioned] by the predetermined multiplier, and obtains a step size is recorded.
[0014]
[Embodiment of the Invention] Hereafter, the gestalt of operation of this invention is explained with a drawing. First, the gestalt of operation of the 1st of this invention is explained. The step size control approach by this invention is the approach of approximating the optimal step size value specifically drawn theoretically.
[0015] First, how in each time of day to choose the optimal step size theoretically is drawn as preparation which describes the step size control approach by this invention. It is theta (n) as a tap weight error now. =h-c (n) A vector is defined. h At the response vector of the unknown system which should ******, die length is the number N of taps. Suppose that it is equal. theta (n) Updating type theta (n+1) =theta (n) -alphac (n) a (en+nun) (n) .... It is (2).
[0016] Next, theta (n) Second-moment matrix K (n) =E [theta (n) theta(n) T] (E[] means expected value) If it attaches, the following difference equation is realized.
K (n+1) =K (n) -alphac+(V(n)+V (n) T) alphac 2T (n) .... (3) It lines up here. V (n) T (n) It is given by the degree type.
V (n) =E [(en+nun) a (n) theta(n) T] T (n) =E [(en+nun) a(n) a (n) T] .... (4) [0017] [2] Furthermore, it is time of day n. The square average error (MSE) which can be set is Ra=E [a (n) a (n) T]. As the covariance matrix (or matrix of correlation) of a filter input signal sequence epsilon (n) =E[en 2] =trace (Ra K (n)) .... It asks by (5). trace() means the sum of the diagonal element of a matrix here.
[0018] Then, time of day n It sets and is epsilon (n+1). In order to ask for the step size made into min, it is time of day n. Step size alphac which can be set (n) Related partial differential coefficient **epsilon (n+1)/ **alphac (n) =trace (Ra **K (n+1)/ **alphac (n)) = trace {Ra (-(V (n)+V (n) T)+2 alphac (n) T (n))} .... By placing (6) with zero, it is the theoretical value of the optimal step size. alphac (n) opt =trace(Ra V (n))/trace (Ra T (n)) .. It is obtained by (7).
[0019] By the way, theta (n) It is a vector when a value is given. a (n) About the related expected value, it is [0020].
[Equation 1]

$$E_a [(e_n + \nu_n) a^{(n)} \mid \theta^{(n)}] \cong Ra\, \theta^{(n)} \quad \cdots\cdots (8)$$

**********. From now on, it will be [0021].
[Equation 2]

$$V^{(n)} \cong Ra\ K^{(n)} \quad \cdots\cdots (9)$$

Since it becomes, the above-mentioned optimal step size is [0022].
[Equation 3]

$$\alpha_c{}^{(n)}{}_{opt} \cong trace(Ra^2\ K^{(n)})/trace(Ra\ T^{(n)}) \quad \cdots\cdots (10)$$

It is expressed.
[0023] The number N of taps It is [0024] when comparatively large (20 or more [for example,]).
[Equation 4]

$$\sigma_\nu^2$$

As power of an additive noise, it is [0025].
[Equation 5]

$$\begin{aligned} T^{(n)} &\cong E[(e_n + \nu_n)^2] E[a^{(n)}\ a^{(n)T}] \\ &\cong (\varepsilon^{(n)} + \sigma_\nu^2) Ra \quad \cdots\cdots (11) \end{aligned}$$

Approximating [therefore], the optimal step size is [0026].
[Equation 6]

$$\alpha_{c.}{}^{(n)}{}_{opt} \cong \mathrm{trace}(Ra^2 K^{(n)})/\mathrm{trace}(Ra^2)/(\varepsilon^{(n)} + \sigma_\nu^2)$$
$$\cong(\pi/2/\mathrm{trace}(Ra^2)) \times (2/\pi)\mathrm{trace}(Ra^2 K^{(n)})/(\varepsilon^{(n)} + \sigma_\nu^2) \quad \cdots\cdots(12)$$

It becomes.

[0027] Then, it sets to the step size control approach of this invention, and is time of day n. The step size which can be set is created by the degree type.

alphac (n) =beta|| q (n) ||2 .... (13) however beta=pi/2-/trace (Ra2), and || q (n) ||2 Vector q (n) It is a norm and a vector. q (n) According to the following recurrence formula, it calculates serially by leakage ******. q (n+1) =(1-rho) q (n) +rhosgn a (en+nun) (n) .... (14) Here rho is a leakage factor and sgn() is a polar function.

[0028] It is step size alphac like an upper type (13). (n) When it makes, it is [0029] to the input signal like a gauss fault.

[Equation 7]

$$E[\| q^{(n)} \|^2] \cong (2/\pi)\mathrm{trace}(Ra^2 K^{(n)})/(\varepsilon^{(n)} + \sigma_\nu^2) \quad \cdots\cdots(15)$$

Becoming is shown and, therefore, it is [0030].

[Equation 8]

$$E[\alpha_C{}^{(n)}] \cong \alpha_C{}^{(n)}{}_{opt} \quad \cdots\cdots(16)$$

It becomes. That is, the step size by this invention becomes equal to the optimal theoretical value in approximation.

[0031] In addition, it can apply also to a probability inclination normalization LMS algorithm, and the step size control approach by this invention is beta= (pi/2) in that case. sigmaa 2 N/trace (Ra2) Then, it is good.

[0032] It is alphaC at an upper type (13). (n) Although it must ask for a multiplier beta beforehand in case it creates, the value of trace (Ra2) is required for it. It shall assume that a filter input signal sequence is known here, and the covariance matrix Ra shall be known. When this value is strange, asking with the following recurrence formula is also possible.

[0033]

[Equation 9]

$$\tau^{(n+1)} = (1-\rho_\tau)\,\tau^{(n)} + \rho_\tau\,(a^{(n-L)T}\,a^{(n)})^2 \quad \cdots\cdots(17)$$

It is here and is [0034].

[Equation 10]

$$\rho_\tau$$

** -- sufficient small leakage factor -- the amount L of delay [0035]

[Equation 11]

$$E[a^{(n-L)T}\,a^{(n)}] \cong 0$$

********** -- it is chosen as a sufficiently large value like. tau after time amount passes enough (n) E [(a(n-L) T a (n)) 2] Converging on =trace (Ra2) is known.

[0036] The block diagram and drawing 2 which show notionally the circuit where drawing 1 performs the step size control approach by this invention show the detailed configuration of drawing 1 . In addition, the norm calculator in drawing 1 and drawing 2 is a computing element for calculating the norm (square sum of each element) of a vector. A norm is called for also by the inner product of a vector and itself. vector q (n) die length -- N it is -- since -- the required number of leakage ****** -- N It is an individual.

[0037] drawing 1 and drawing 2 -- setting -- 10 and 11 12 [and] -- leakage ****** -- it is -- 1 Input en+nun and 20 -- a polar detector (sgn()) and 2 -- polar output sgn (en+nun), and 101,111 and 121 -- respectively -- input an and an-k and -- an-N +1 it is . 112,113 And 114 A multiplier and 115 An adder and 116 The delay circuit of unit time amount, and 117 Leakage factor (rho) 118 -- complement (1-rho) of a leakage factor it is . 109,119 And 129 It is the output of leakage ******, respectively. 30 -- the norm calculator of a vector -- it is -- 109, ..., 119, ..., 129 from -- the norm of the becoming vector is calculated and 31 is outputted. Moreover, 40 is a multiplier and 3. It is a multiplier beta and is 4. It is the step size obtained as an output.

[0038] Drawing 3 is a flow chart which shows drawing 1 and the operation process which the circuit of drawing 2 performs. First, it is a vector at step S1. sgn(en+nun) a (n) It calculates, this vector is used and it is vector || q (n) by leakage ****** 10, 11, and 12 at step S2. ||2 It asks. Next, the vector searched for is used and it is norm || q (n) by the norm calculator 30 at step S3. ||2 Norm || q which calculated and carried out [above-mentioned] count by step S4 (n) ||2 It multiplies by the multiplier beta with a multiplier 40, and is step size alphac. (n) It asks and outputs at step S5.

[0039] The simulation result of the convergence process of an adaptation filter shows the effectiveness of the gestalt of this operation. A signal sequence assumes an additive noise to be Gaussian noise like a white gauss fault. As a typical parameter value, it is the number of taps. N= 32 [0040]

[Equation 12]

未知システム応答ベクトル $h^T h \cong 1$

Power of an input signal sequence sigmaa 2 =1(0 dB) [0041]
[Equation 13]
相加雑音の電力 $\sigma_\nu^2 = .01(-20\ \mathrm{dB})$

When a step size is immobilization In the case of the adaptive control step size by alphac =2 -11 this invention rho= 2-11 was used.
[0042] A simulation result is shown in drawing 4 . It when a broken line a performs step size control according [a continuous line b] the situation of convergence of a square average error (MSE) in case a step size is immobilization to this invention is shown. In the latter, while a convergence rate is accelerated remarkably, MSE after convergence is equivalent to the former. In addition, theoretically, if a leakage factor rho is chosen greatly, although convergence becomes quick, it turns out that MSE after convergence increases. If in charge of the above-mentioned step size creation, it is the number N of taps. Although considered as size, even if it is number tap extent in practice, effectiveness as shown in drawing 4 is acquired.
[0043] According to the adaptive control approach of the step size by this invention, MSE after convergence is stopped small and the quick probability inclination LMS algorithm adaptation filter of convergence is obtained so that clearly from the above-mentioned example. Moreover, this control approach is further applicable also to a probability inclination NLMS algorithm adaptation filter as mentioned above.
[0044] Next, the gestalt of operation of the 2nd of this invention is explained with drawing 5 . Drawing 5 shows the gestalt of operation in case a microcomputer (microcomputer) performs step size control of the adaptation filter in the gestalt of the 1st operation mentioned above.
[0045] It sets to drawing 5 and is the adaptation filter 500. Microcomputer 501 A step size is controlled. Microcomputer 501 It has a function equivalent to drawing 1 by the gestalt of the 1st operation, and drawing 2 . And microcomputer 501 Record medium 502 according processing by the flow chart of drawing 5 to this invention It performs by being controlled by the recorded program.
[0046] Record medium 502 If it carries out, ROM, RAM, a flash memory, a memory card, an optical disk, a magneto-optic disk, a magnetic-recording medium, etc. can be used.
[0047]
[Effect of the Invention] As explained above, the step size of an adaptation filter can be approximated to a theoretical optimum value, and in early stages of convergence, the value of a step size is small controllable [for this reason] according to this invention, as it is large and convergence progresses. And since the step size near an optimum value is used, convergence quicker than the case where a step size is immobilization can be obtained.

[Translation done.]

CLAIMS

[Claim(s)]
[Claim 1] A detection means to detect the polarity of the error signal of a filter output signal and a strange signal, The 1st multiplication means which multiplies the polarity which carried out [above-mentioned] detection by the filter input signal vector, and acquires the vector of a product, The adaptation filter characterized by establishing a leakage **** means to equalize the vector of the above-mentioned product, an operation means to compute the norm of the vector of the product which carried out [above-mentioned] equalization, and the 2nd multiplication means that multiplies the norm by which calculation was carried out [above-mentioned] by the predetermined multiplier, and obtains a step size.
[Claim 2] The step size control approach characterized by having the procedure which calculates the norm of the vector which equalizes the vector of the product which multiplies the polarity of an error signal by the filter input signal vector, and is obtained in the step size control approach in an adaptation filter, and is acquired, and the procedure of multiplying the above-mentioned norm by the predetermined multiplier, and obtaining a step size.
[Claim 3] The detection processing which detects the polarity of the error signal of the filter output signal of an adaptation filter, and a strange signal, The 1st multiplication processing which multiplies the polarity which carried out [above-mentioned] detection by the filter input signal vector, and acquires the vector of a product, The record medium which recorded the program for performing leakage **** processing which equalizes the vector of the above-mentioned product, data processing which computes the norm of the vector of the product which carried out [above-mentioned] equalization, and 2nd multiplication processing which multiplies the norm by which calculation was carried out [above-mentioned] by the predetermined multiplier, and obtains a step size.
[Claim 4] The adaptation filter according to claim 1 characterized by having a non-recursive filter and using a probability inclination LMS algorithm.
[Claim 5] The adaptation filter according to claim 1 characterized by having a non-recursive filter and using a probability inclination normalization LMS algorithm.
[Claim 6] The above-mentioned adaptation filter is the step size control approach according to claim 2 have a non-recursive filter and using a probability inclination LMS algorithm.
[Claim 7] The above-mentioned adaptation filter is the step size control approach according to claim 2 have a non-recursive filter and using a probability inclination normalization LMS algorithm.

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